

FINAL REPORT

ELECTRONIC TARGET SIGNAL GENERATOR  
(ETSG) DESIGN AND ANALYSIS

by

G.E. Riley and M.J. Sinclair

Contract Number DAAK40-78-D-0008

Delivery Order No. 0002

Georgia Tech Project No. A-2186

Prepared for

U.S. Army Missile Command  
System Simulation Directorate

ATTN: DRDMI-TDF

Redstone Arsenal, AL 35809

Prepared by

GEORGIA INSTITUTE OF TECHNOLOGY  
Engineering Experiment Station  
Atlanta, Georgia 30332

May 1980

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle)  Electronic Target Signal Generator (ETSG) Design and Analysis		5. TYPE OF REPORT & PERIOD COVERED  Final Technical Report
7. AUTHOR(s)  G.E. Riley and M.J. Sinclair		6. PERFORMING ORG. REPORT NUMBER A-2186
9. PERFORMING ORGANIZATION NAME AND ADDRESS Georgia Institute of Technology Engineering Experiment Station Atlanta, GA 30332		8. CONTRACT OR GRANT NUMBER(s) DAAK 40-78-D-0008 Delivery Order No. 0002
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Missile Command ATTN: DRDMI-TDF Redstone Arsenal, Ala. 35809		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE April 1980
		13. NUMBER OF PAGES 54
		15. SECURITY CLASS. (of this report)  Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Electronic Target Signal Generator (ETSG) Electro-Optical Seeker Aircraft Targets Countermeasures		
Conical Scan Rosette Scan Flight Simulation		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		

## FOREWORD

This report was prepared by the Engineering Experiment Station at Georgia Tech under Contract DAAK40-78-D-0008, Delivery Order No. 0002. The work described was performed in the Electro-Optics Division of the Electromagnetics Laboratory under the supervision of G.E. Riley, Program Director. The objectives and results of this work cover the design and analysis phase of the Electronic Target Signal Generator (ETSG) development. The assistance and technical contributions of Mr. Don Dublin, technical monitor at MICOM is gratefully acknowledged. The contributions of J.E. Tumblin and G.R. Loefer were most helpful during this phase of the program.

## TABLE OF CONTENTS

	PAGE
1.1 INTRODUCTION AND SUMMARY-----	1
2.1 CONCEPTUAL DESIGN-----	4
2.1.1 Initialization-----	6
2.1.2 Dynamic Processing-----	6
2.1.3 Scan and Convolution-----	8
2.2 SIMULATION RESOLUTION-----	9
2.2.1 Optical Resolution-----	9
2.2.2 Target Size and Orientation-----	10
2.2.3 Source Intensity Scaling-----	13
2.3 DATA RATES-----	18
2.3.1 Target Processor Data Rates-----	21
2.3.2 Convolution Processor Data Rates-----	21
3.1 DESIGN IMPLEMENTATION-----	25
3.2 SIMULATION INITIALIZATION-----	25
3.2.1 Seeker Scaling-----	25
3.2.1.1 Seeker FOV and Optical Resolution-----	27
3.2.1.2 Seeker Scan-----	28
3.2.1.3 Seeker Sensitivity-----	28
3.2.2 Environmental and Background Scaling-----	30
3.2.3.1 Atmospheric Attenuation-----	30
3.2.3.2 Background Irradiance-----	31
3.2.3 Target Scaling-----	31
3.2.3.1 Shapes and Gradients-----	31
3.2.3.2 Total Intensity-----	32
3.2.3.3 Programmable Intensity-----	38
3.2.3.3.1 Flares-----	38
3.2.3.3.2 Pulse Jammer-----	38
3.2.3.4 Aspect Scaling-----	40
3.2.3.5 Complex Targets-----	40
3.2.3.6 Polarity and Spectral Type-----	41
3.3 TARGET CPUS-----	41
3.4 TARGET LOADERS-----	42
3.4.1 Variable Path Addressing-----	42
3.4.2 Priority Encoding and Loading-----	47



3.5	CONVOLUTION PROCESSING-----	47
3.5.1	Rosette Scan-----	49
3.5.2	Conical Scan-----	49
3.5.3	Summation-----	50
3.5.4	Conversion For Output-----	51
3.6	COLOR DISPLAY AND ERROR PROCESSING-----	52
4.1	CONCLUSIONS-----	54

## LIST OF FIGURES


	PAGE
Figure 1	ETSG Flight Simulation Interface----- 3
Figure 2	ETSG Conceptual Design----- 5
Figure 3	Simulation Optical Resolution----- 11
Figure 4	Digital Effects on Targets----- 12
Figure 5	Seeker Irradiance vs Range----- 14
Figure 6	Intensity Scaling Accumulator----- 17
Figure 7	ETSG Design Implementation----- 26
Figure 8a	Triangular Target with Linear Gradients----- 33
Figure 8b	Rectangular Target with Linear Gradients----- 34
Figure 8c	Rectangular Target with Gaussian Gradients----- 35
Figure 8d	Elliptical Target with Gaussian Gradients----- 36
Figure 8e	Circular Target with Linear Gradients----- 37
Figure 9	Flare Time History----- 39
Figure 10	Scaled Target----- 44
Figure 11	Target Location----- 45
Figure 12	Key Point Location----- 46
Figure 13	Target Rotation----- 48

## LIST OF TABLES

	PAGE
Table I      Simulation Initialization Parameters-----	7
Table II     Optical Parameters-----	19
Table III    Rosette Scan Parameters-----	22
Table IV     Conical Scan Parameters-----	23

## SECTION I

### 1.1 INTRODUCTION AND SUMMARY

The conceptual design of a flexible, programmable, hybrid computer controlled Electronics Target Signal Generator (ETSG) for electro-optical seeker simulation work at MIRADCOM has been completed. The ETSG generates a simulated signal equivalent to the detector output of a variety of electro-optical seekers such as  as well as known or postulated electro-optical threat seekers.

The basic concept for the ETSG is a hybrid general purpose and special purpose computer which can create and control up to 20 sources of specified shape, size, spatial orientation, spatial position, intensity, and intensity gradients. The simulation of a particular target/background/countermeasure scenario can be made by selecting, at the outset, combinations of sources to represent the various parts of the total signature.

These sources may represent simple targets, complex targets made up from more than one source with a designated control point for the combination of sources, infrared flares, or pulsed jammers. Sources may be designated as belonging in a single spectral band or divided into two independent spectral bands. All twenty channels have the capability of being designated as band one or band two. Band one is unipolar and band two bipolar. When sources are split between spectral bands, the ETSG supplies two independent outputs, one for each spectral band. Output polarity may be reversed by a hardware switch on the final digital-to-analog converter board which interfaces with the seeker electronics.

In general, aircraft type targets are made up from five sources,

one each for the fuselage, canopy, and plume, and two sources to represent the wings. These five sources are then assigned a single control point for all five sources. A single set of target coordinates, aspect orientation angle and bank angle are calculated and transmitted to the ETSG independently for all five channels making up the complex target. The ETSG then performs all functions necessary to fly the five sources as one.

Sources used to represent countermeasures (pulsed jammers or flares) will utilize a single ETSG channel when a single spectral band is being simulated and two ETSG channels if a dual spectral band is being simulated. When simulating a non-expendable pulse jammer, computational power may be conserved by designating the pulse jammer as part of the complex target. Alternately, the pulse jammer may have coordinates anywhere on the aircraft with independent coordinates being calculated and transmitted to the ETSG. Flare sources are controlled independently. Coordinates are calculated in the CDC-6600 by giving each flare initial conditions equal to the dispensing aircraft and calculating its new position from known drag equations. Each flare is turned on by command from the CDC-6600 and has the capability of being re-cycled once the flare has dropped beyond the tracking field of view.

The entire flight simulation and how the ETSG interfaces with it is shown in Figure 1. An operator's console and display are used to initialize the simulation, and display dynamic position of the seeker field-of-view (FOV) and each target/source position relative to the FOV center. The simulation must be initialized for seeker, target, flare and pulse jammer parameters. After initialization the ETSG accepts dynamic target/source parameters from the CDC-6600 via the Direct Cell Interface. These parameters are then mapped onto a memory representing the seeker image plane. This image plane is then convolved with the seeker scan pattern which may be a reticle or other scan patterns such as a rosette. For scan systems other than reticles, scan signals must be supplied to the ETSG via the seeker electronics or other electronics external to the ETSG. Using either prestored reticle patterns or scan signals, the scan

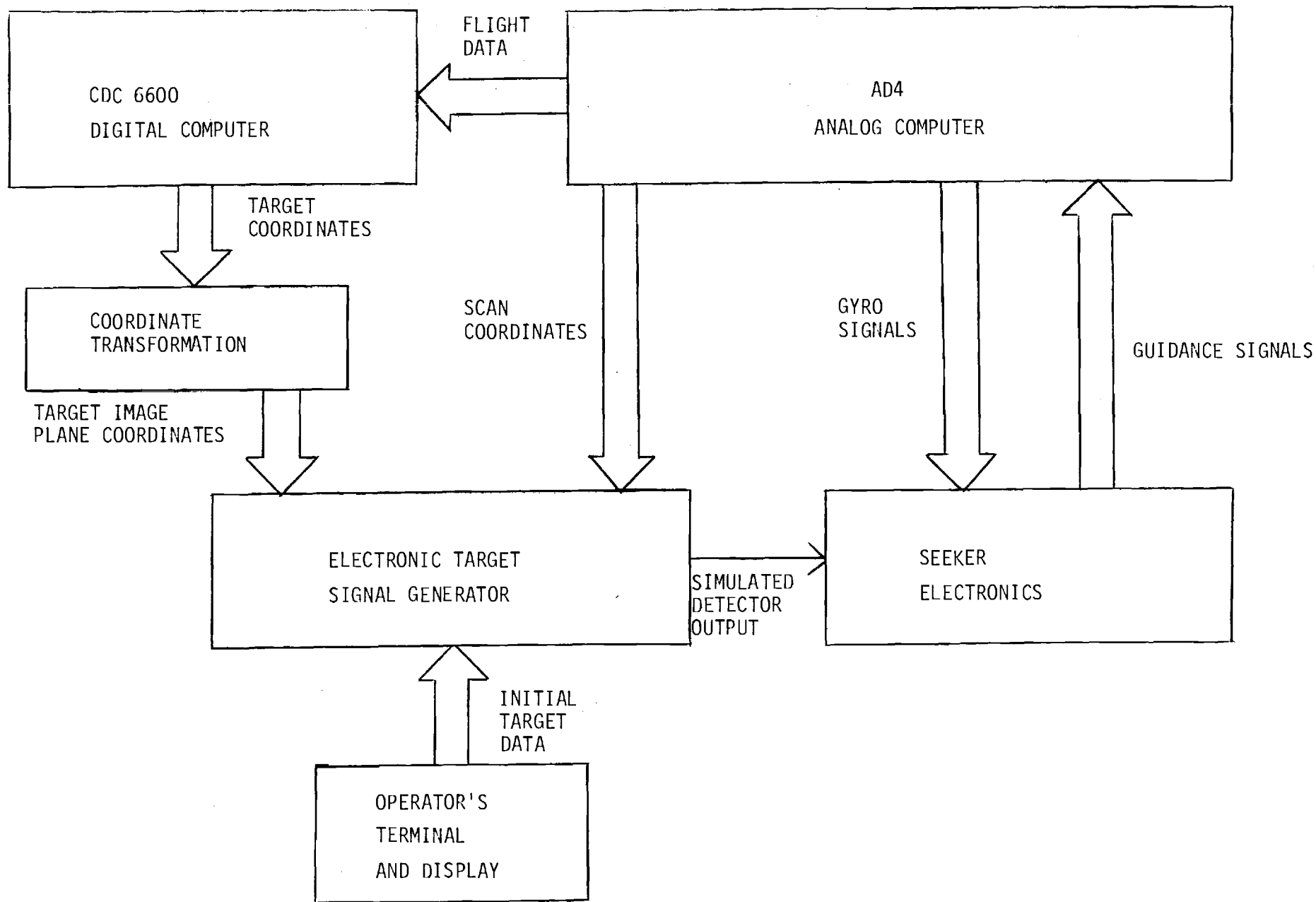


Figure 1. ETSg Flight Simulation Interface

is convolved with the seeker image plane. The resulting digital signal is converted to an analog signal, ripple filtered and output as the seeker detector signal. This simulated detector signal is supplied directly to the seeker preamplifier and processed to generate a gyro precession command. The precession command is then supplied to the AD-4 analog computer to close the tracker loop and produce guidance commands. The CDC-6600 accepts guidance commands and calculates a new airframe position. New target image plane coordinates are then calculated and supplied to the direct cell interface for temporary storage.

These calculations are performed on a nominal 2 ms interval preset at the ETSG hardware. At the end of each 2 ms interval, the ETSG accepts data on command from the direct call data ready line. The ETSG then buffers each frame of data from the direct cell and accepts the latest complete data frame for calculations.

## SECTION II

### 2.1 CONCEPTUAL DESIGN

The Electronic Target Signal Generator (ETSG), as designed, is a self-contained electronic device which, when given the proper initial and dynamic analog and/or digital inputs, will generate an electrical analog voltage which simulates the detector output of several types of electro-optical seekers. The ETSG will respond to computer (analog/digital) inputs for initial setup prior to a simulation run and is designed in such a manner as to be capable of computer controlled maintenance and fault diagnosis. To accomplish these goals the ETSG is divided into major subsections as shown in Figure 2. The three distinct phases for a particular simulation are: 1) initialization, 2) dynamic source update and 3) scan convolution processing. The purpose of each major function is described at an introductory level below. Section III gives a more detailed description of parameters and how they are to be implemented in hardware.

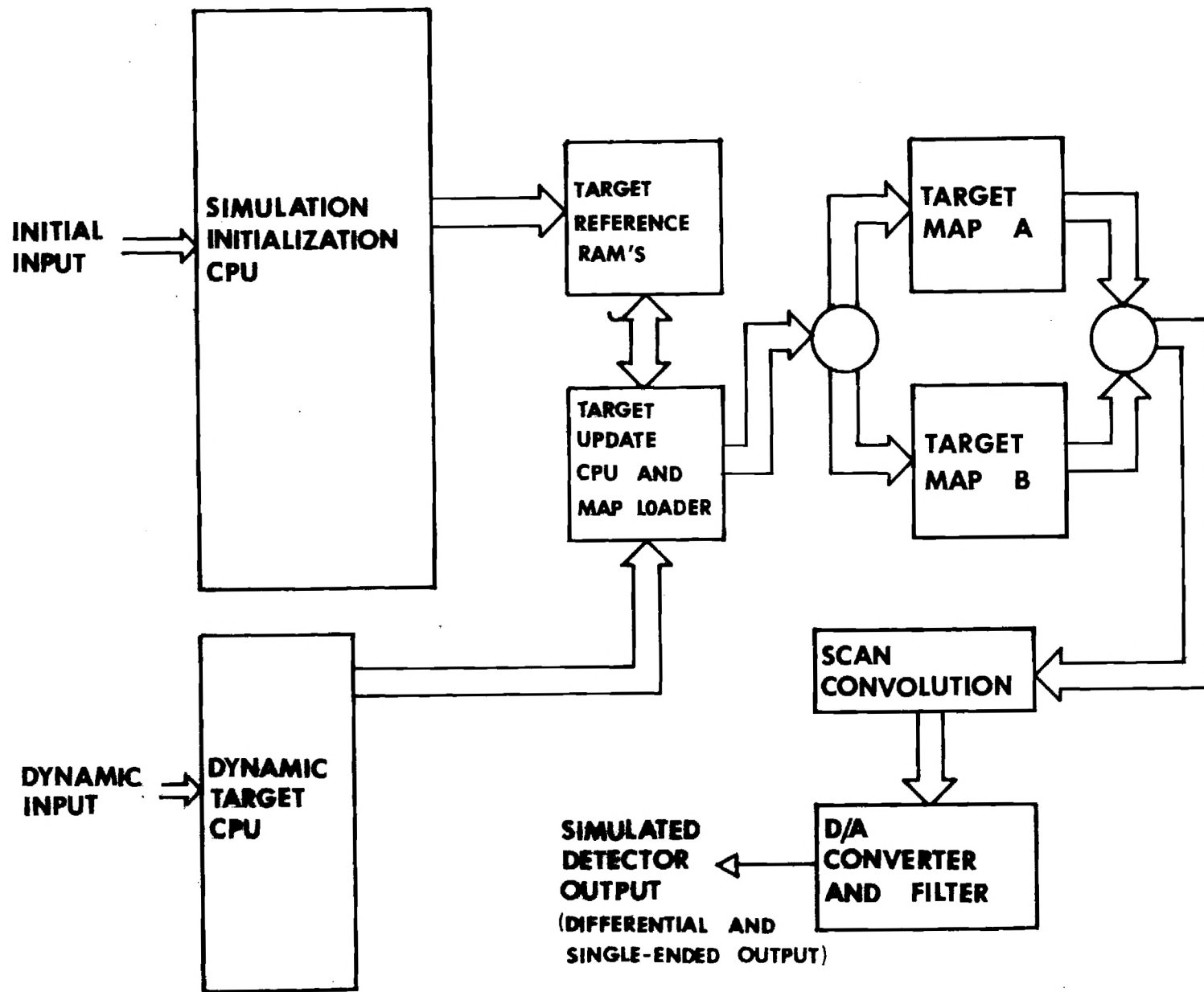


Figure 2. ETSG Conceptual Design



### 2.1.1 Initialization

During initialization, constants, as in Table I, which select a particular seeker type and describe the desired source properties are entered. Using these inputs, a lookup RAM is generated for each target to avoid unnecessary calculations during target/source updates.

The target lookup RAM is a 64 x 64 block of 8-bit memory for each possible target. This block contains the highest resolution map that the target can have during the mission. This reference is scaled in size, intensity and orientation during the run to produce dynamic sources.

During initialization, the I/O CPU (Input/Output Central Processing Unit) loads the lookup RAM, calculating one of three shapes: triangle, rectangle or ellipse, and applying the true aspect ratio. In addition, to produce a more accurate rendition of the true target during fly around, the triangle has two additional views (circles) which are combined to simulate fly around. Once the shapes have been described, the loading processor calculates the total target power and distributes normalized numbers according to the specified gradients.

### 2.1.2 Dynamic Processing

During a target update, the target CPU processes each target lookup RAM with the dynamic variables of range, position, aspect orientation, and rotation orientation and loads the result into a target buffer. This contains all the targets within the seeker FOV in preparation for the convolution. There are two identical buffers which are addressed by either the target CPU or the convolving CPU on alternate frames.

The 64 x 64 point lookup RAM represents the target at minimum range. Therefore, the size of the target at any other range during the simulation will be less than or equal to this maximum size. Also, the lookup RAM is for the target viewed with no projection. Thus any projected


TABLE I  
SIMULATION INITIALIZATION PARAMETERS

---

INITIAL INPUTS

---

SEEKER PARAMETERS

Type	Rosette, Conical or Center Spun
FOV	Scaled to IFOV
Blur	0.5 mrad. Minimum
NEFD	Any Value
SNR for Track	1 to 10 <sup>10</sup>
Reticle Scan Rate	
System Responsivity	Any Value

SOURCE PARAMETERS

Shape	Elliptical, Rectangular, or Triangular from Library Diagram
Size	Any Size (Linear Dimensions)
Aspect Ratio	1:1 to 32:1
Intensity Gradients	Programmable
Spectral Bands	Any Two
Intensity Polarity	Plus or Minus
Programmable Intensity	Complex
Maximum Range	Meters
Minimum Range	Meters

PULSE JAMMER

Rep Rate	20 kHz Maximum
Sweep Time	Scan Rate + 20%
Duty Cycle	Maximum 50%
Period	1.6 Sec Maximum

FLARES

Intensity vs. Time	20 Seconds Maximum
--------------------	--------------------

aspect ratio will be less than or equal to the reference. Therefore, any target can be created from the reference simply by skipping points in the reference as the target is loaded into the target buffer. The skip factor can be an integer value, but this is generally too crude to produce proper scaling. However, by expanding the length of the word used to calculate the next reference point, a "fixed point" calculation can be done with much improved accuracy for virtually no loss of speed.

After the target is properly scaled in size and aspect, it must be rotated to simulate actual target orientation. This would normally require calculation of sines, cosines, several multiplications and several additions for each of the 64 x 64 (4096) target points. This requires calculation speeds far beyond current hardware capabilities. Fortunately, a much simpler algorithm, using variable path addressing, can not only perform the rotation, but can also assist in the size scaling.

As the target is loaded into the target buffer, the intensity from the lookup RAM is contrasted with the background, scaled for range (with atmospheric effects included) by a floating point multiply.

When all twenty targets have been loaded, the convolution should also be completed and the target CPU and convolver simultaneously swap buffers. The new target buffer is cleared and the target inputs are updated. The loading process is then completed.

### 2.1.3 Scan and Convolution

Up to this point all the processing (except frame rates) have been the same for all systems. In the rosette system, a relatively small (3 x 3) window must be scanned in a rosette path through the FOV. The points which fall within the window are summed and output as a single time sample.

The conscan system requires an algorithm that is almost identical to the rosette, except that the areas of complexity have changed. The conscan reticle moves through the field-of-view along a simple path

(around a circle of fixed radius at a constant speed). The reticle is essentially a large (64 x 64) mask in which certain portions have been blacked out. All the points which show through are summed and output as a single time sample.

After all the points are summed, the background level is added, the result converted to an analog signal and filtered to remove digital sampling noise. This then is the simulated detector output.

## 2.2 SIMULATION RESOLUTION

Simulation resolution requirements and resulting data rates are determined by the systems to be simulated. These parameters include optical resolution, source intensity, and intensity gradient resolution. Each of these parameters and its resulting impact on system design and data rates are discussed in the following sections.

### 2.2.1 Optical Resolution

Simulation resolution requirements for an electro-optical system can be determined by considering the transfer functions of sub-systems. In general, the optical transfer function will determine the system information rate and consequently the simulation resolution. The magnitude of the point spread function, PSF, for a circular aperture for a wide spectral band can be approximated by a Gaussian function<sup>1-3</sup>.

$$|\text{PSF}| = \frac{1}{2\pi\sigma^2} \exp(-\rho/2\sigma^2)$$

where  $\sigma$  is the standard deviation of a Gaussian function  
dependent on the spectral bandwidth and aberrations  
of the optical system.  
 $\rho$  is the blur circle radius.

Equation (1) adequately represents the incoherent optical systems being considered here. Transforming this equation to the spatial frequency domain<sup>4-5</sup> and normalizing yields the modulation transfer function (MTF):

$$MTF = \exp [-2\pi^2(f_s \sigma)^2]$$

where  $f_s$  is the spatial frequency in cycles/radian. Figure 3 shows the transfer function for 0.25, 0.5, 1.0 and 2 milliradian optical blur diameters. These plots clearly show that in systems with resolution of 1 mrad. or greater, a 0.25 milliradian simulation is not justified. This increase in simulation resolution would increase the simulation data rates by a factor of four. This increases both the target processor and convolution hardware by a factor of four and severely impacts cost.

The plots in Figure 3 can be converted to time domain signal by the seeker scan velocity. Independent of the seeker electronics transfer functions, Figure 3 represents the maximum information content for a given signal. The signals can only be degraded further by electronics. In the rosette scan system, Figure 3 shows that the sampling ripple can be filtered by approximately one order of magnitude.

### 2.2.2 Target Size and Orientation

Most problems associated with target parameters stem from the digital nature of the ETSG. The effect is most dramatic in smaller targets. Figure 4 shows two digital circles, one of radius 5, the other is radius 8. Notice that the appearance of the larger circle is much more aesthetically pleasing. At radii of less than 5, "circles" become indistinguishable from "squares" and other shapes. Thus, aspect ratios at small sizes are often meaningless or take large leaps as a single point is added.

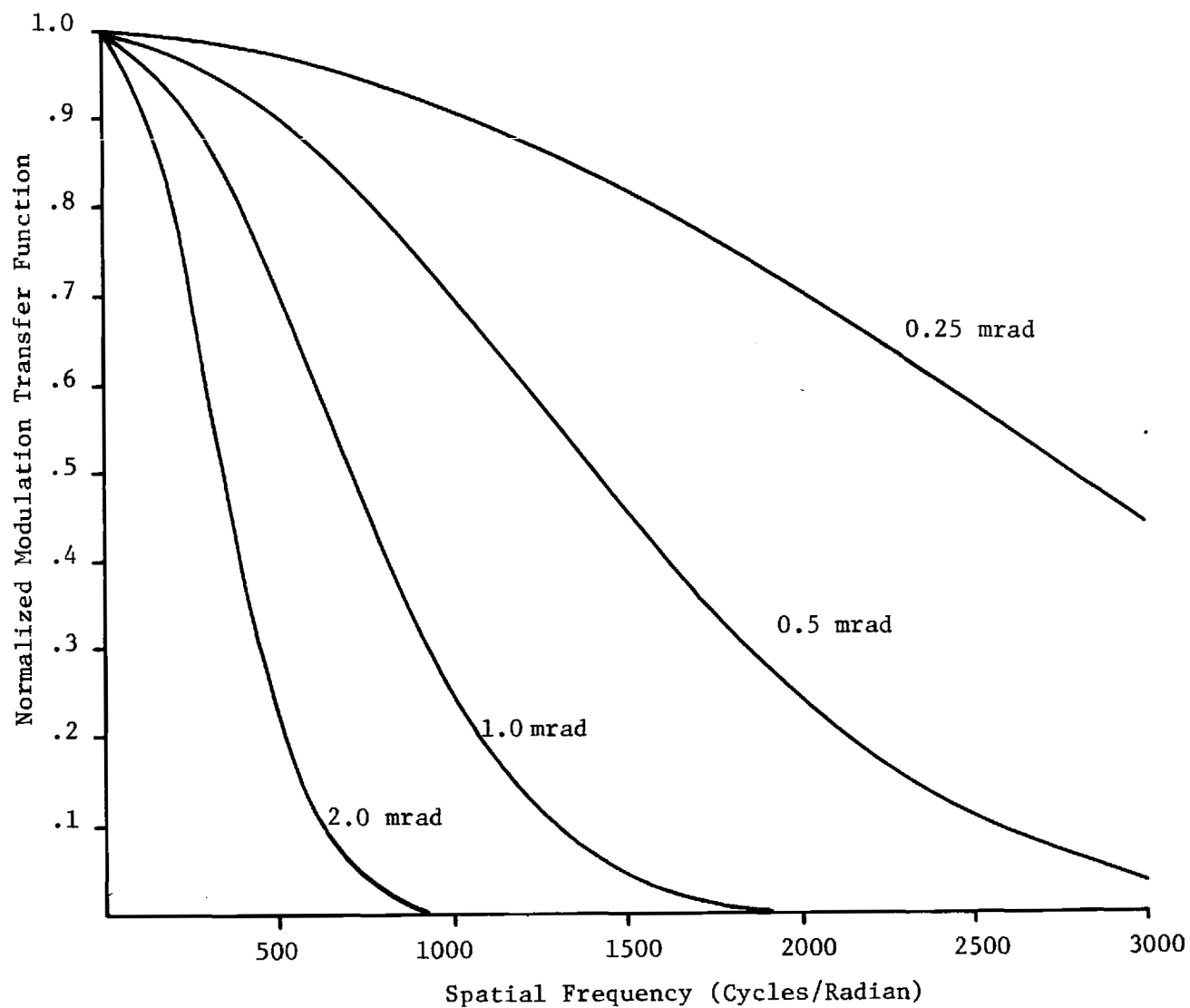
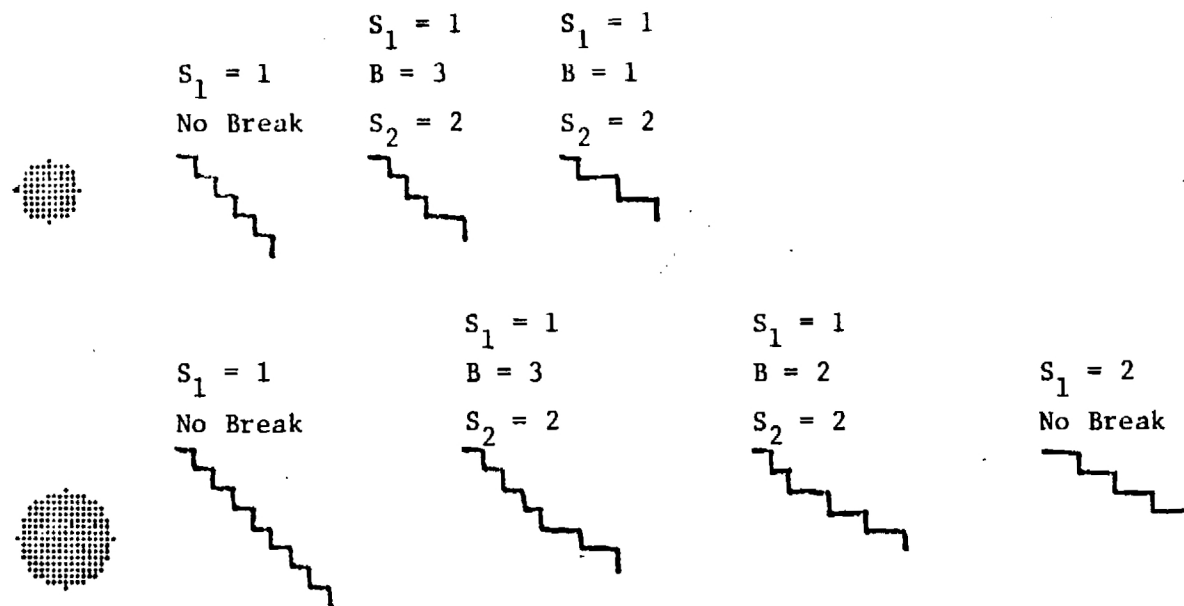


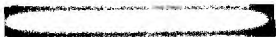
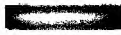
Figure 3. Simulation Optical Resolution



$S_1$  and  $S_2$  are the Gradient Slope Spatial Increments  
 $B$  is the slope breakpoint.

Figure 4. Digital Effects on Targets

Another problem at the small sizes is that the allowable size changes are rather abrupt. Going from a 2 x 2 square to a 3 x 3 square is an increase of 50% in width and an increase in area of 125%. Figure 4 also shows the problems involved with trying to specify intensity gradients across small targets. The figure shows two targets and the smallest linear slopes possible. The specified slopes are shown as integer increments with a break point given when two slopes are attempted. As can be seen, the slopes shown contain little information, especially when compared to slopes possible on a larger target.

The input target coordinates (azimuth angle and elevation angle) are accurate up to 1/64th of the seeker FOV (unless scaled less than 64). The aspect orientation angle accuracy is determined by the size of the trig function lookup ROM, which has an accuracy of  $1.8^\circ$  increments. Rotation orientation in the rosette case has the same accuracy as the spin and roll rate signals. In the conscan system the rotation orientation of the targets is updated at the frame rate . If missile roll is 20 Hz, the roll information is only sampled  per roll cycle. In the rosette system, the roll effect on target rotation is integrated with the scan, and is therefore "updated" at the scan rate.

### 2.2.3 Source Intensity Scaling

Target intensity dynamic range will be controlled over approximately 10 orders of magnitude. The simulator software will convert background radiant intensity, signal to noise ratio (SNR) and seeker NEFD into an equivalent contrast intensity for each target.

Figure 5 shows the seeker irradiance from a normalized 1 watt/steradian point target as a function of range for a clear atmosphere. This plot shows that, with clear atmosphere, range closure from 3 km to 1 meter range requires a simulation dynamic range of seven orders of magnitude. Since the maximum possible simulation dynamic range is  $4 \times 10^9$ , it may be important to determine how this dynamic range is



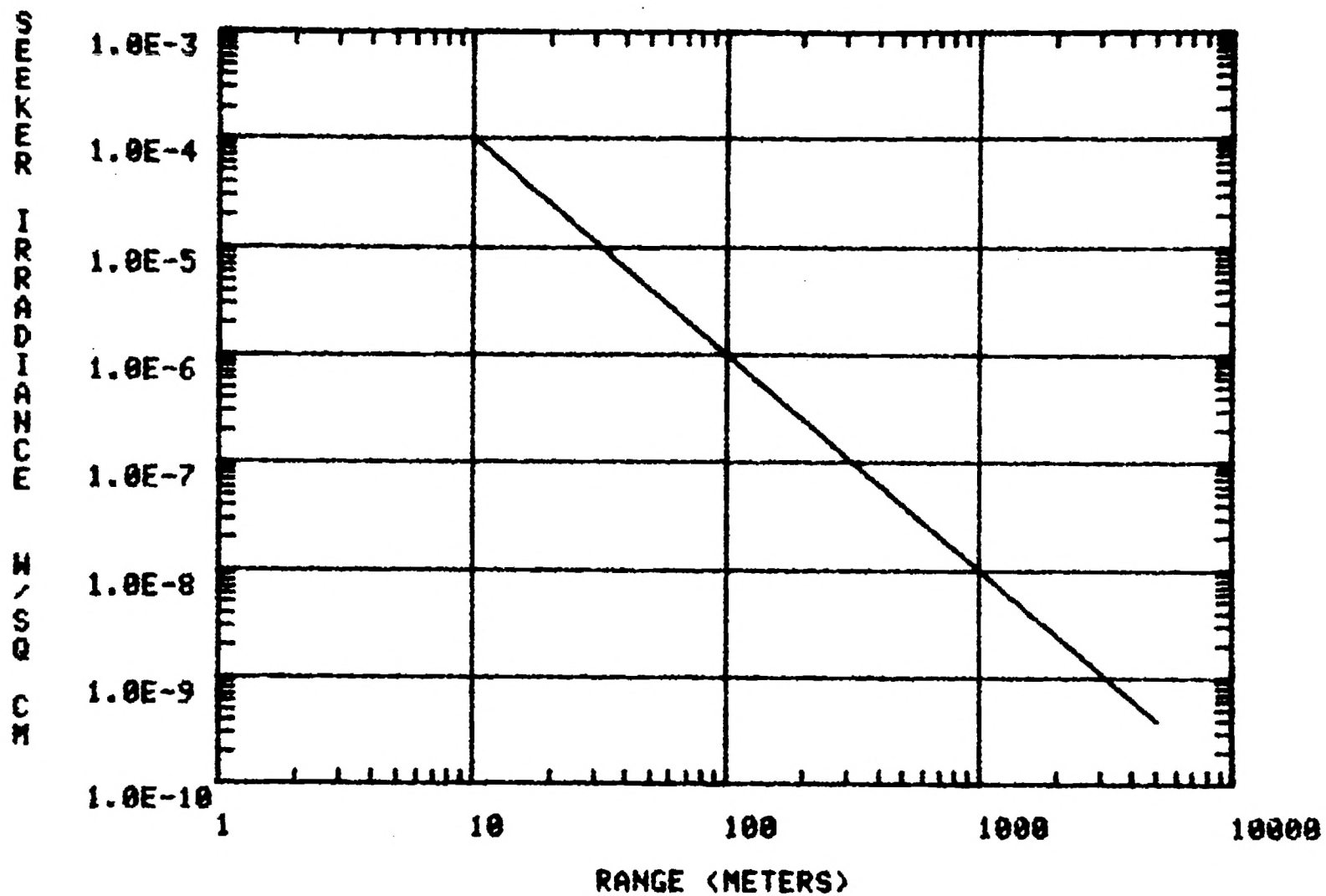


Figure 5. Seeker Irradiance vs Range

divided between range closure and contrast between targets. For point targets the trade-off is minimum range simulated. Figure 5 shows that 2 orders of magnitude in dynamic range are required to simulate one order of magnitude in range closure. For example, if a 1 meter minimum range and a maximum range of 3 km is to be simulated, all source intensities must be within  $4 \times 10^2$  of the target. If countermeasures are to be evaluated and greater than two orders of magnitude in jammer intensity above the target is desired, the simulation must be cut-off at less than 1 meter.

As the missile closes range on an extended, optically resolved target, power collected from any point within a resolution element increases inversely proportional to range squared. However, the number of simulation points within a target area subtended by each resolution element decreases proportional to range squared. Consequently, the image intensity for each resolution element within the simulation will remain constant. Target intensity then becomes an area function in the target scaling. After resolving the target, each resolution element, within the simulation, will be constant and more simulation resolution elements will be added as the target fills the FOV. Therefore, the actual simulation dynamic range will be nine orders of magnitude plus for extended targets. For example, if the optical resolution is 1 mrad. and the target is one meter, the target is resolved at 1 km. At this range six orders of magnitude are left, and may be used for jammers with intensities six orders of magnitude above the target. In this situation the simulation has an effective dynamic range of 1 to  $10^{13}$ .

Various binary compression schemes were investigated to find a numbering system capable of representing the nine orders of magnitude dynamic intensity range of a target simulation, yet convenient enough to utilize available hardware. Eight bit numbers, or bytes, are an ideal base for such a system, as much of the digital hardware commercially available is byte oriented.

A numbering system found to be an efficient utilization of the byte

involves a normalized floating point binary number system. The five most significant bits of the number represent the power of two which is multiplied by the value of the three least significant bits plus eight. More succinctly, if the eight bit number has the bits  $d_7, d_6, d_5, d_4, d_3, d_2, d_1$ , and  $d_0$ , then the value of the number is given by

$$(8 + d_2d_1d_0) \times 2^{d_7d_6d_5d_4d_3}$$

For example, the number 163 (010101011 binary) converts to

$$(8 + 3) \times 2^{10} = 11,264$$

The minimum number is eight and the maximum number is  $15 \times 2^{31} = 3.22 \times 10^{10}$  which gives a dynamic range of  $4 \times 10^9 (3.22 \times 10^{10} \div 8)$ . As with all floating point systems, this system is logarithmic in nature and all real-time intensity calculations are carried out in base 2 logarithms.

In actuality, the number zero (which represents eight in the number system) must be redefined as truly being zero so that background in the target lookup RAM's and target map may be zeroed.

The only significant error introduced by this intensity scaling concept is that potentially differences in intensity of 256:1 cause the lower value to be lost. However, since each resolution element is mapped into 4 simulation resolution elements, adjacent optical resolution elements must be a factor of 512 smaller to be lost. Figure 6 illustrates a partial accumulation over 1/16 the total FOV. The process begins by testing the current input against the current sum.

If the current sum is larger than the input, the input value is tested to determine if the input is 1/256 of the current sum. If yes, the input is considered to be insignificant and the scan continues. If no, the input is added to the current sum. A similar flow occurs if the present sum is insignificant and it is replaced by the current value. A similar accumulator is used to sum outputs from the 16 partial accumulators. However, the final accumulator is expanded to 12 bits to present

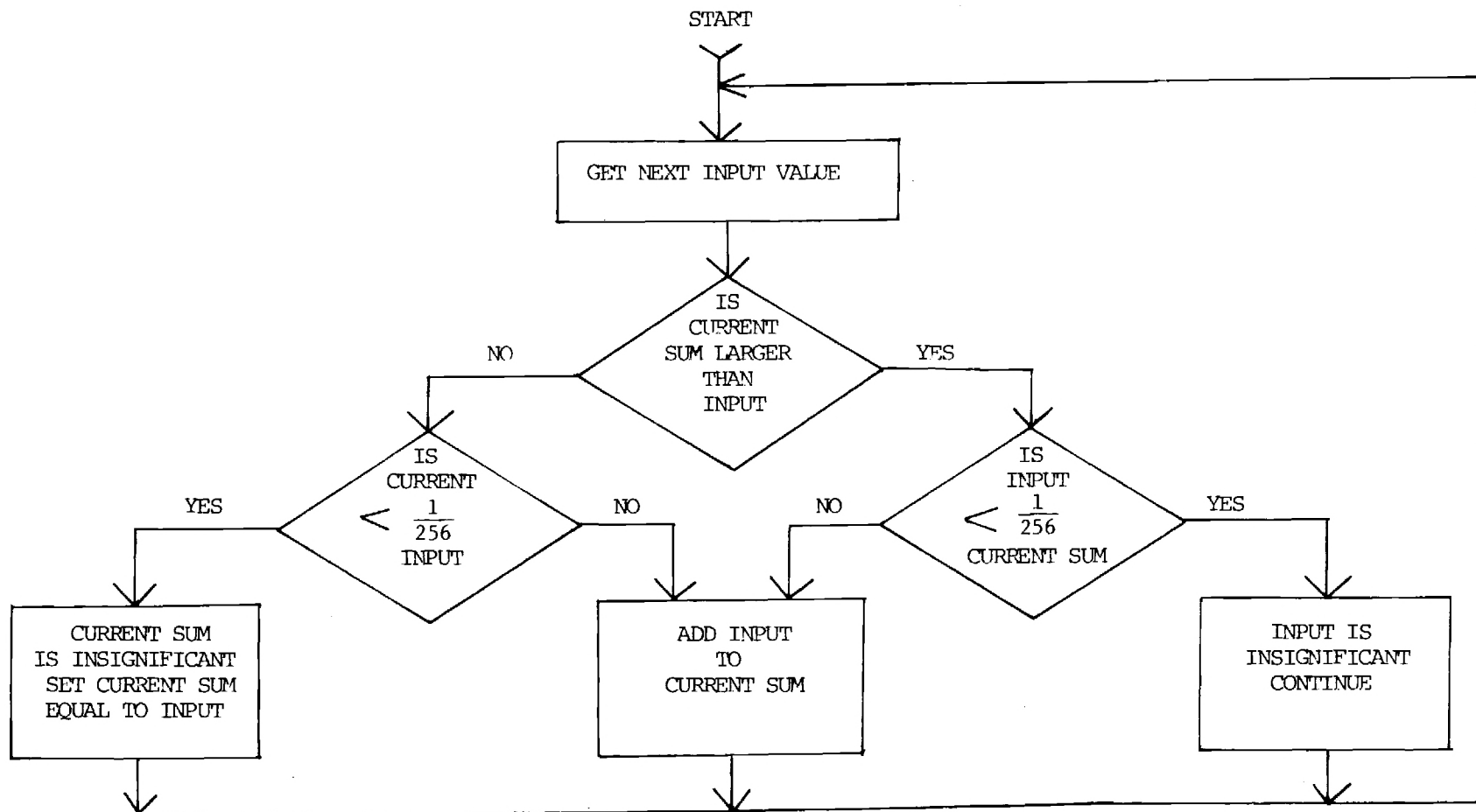


Figure 6. Intensity Scaling Accumulator


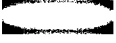

loss of data over an entire FOV. This allows one part in 4096 to be maintained from each of the 16 FOV segments. An unlikely worse case situation would be one where a target and a string of eight flares are contained within a strip across 1/16 the total FOV. For this case, if the combined power from the 8 flares create an instantaneous J/S ratio of 512:1, the target would be lost. This is not likely since the target and flares must be contained within a 1/8 degree segment of the FOV and each flare create a J/S of 16:1. Additionally 512:1 represents an instantaneous dynamic range that the seekers in question are incapable of resolving. Therefore it has been concluded that this system is adequate for all desired reticle simulations. This condition does not apply to the scanning systems such as the rosette. In this case, a flying spot scanner, the pixel to pixel variations can include the entire dynamic range of approximately  $10^{10}$ .

### 2.3 DATA RATES

Data rates for each section of the simulator can be found from the optical parameters and knowledge of scan rates and general system architecture. Table II shows all pertinent seeker optical data. Spin rate for a rosette scan can be thought of as the number of center crossings made by the detector window each second, or the petal rate.

In addition, for real-time simulation of an optical system, the maximum amount of time required between changes in the input and the corresponding change in output, or total system delay, can not exceed two total field of view (TFOV) frame times. Because of this, long queues of data may not be used to simplify parallel processing schemes. If all optical transformations are to be done digitally, then the seeker's continuously changing panorama must be sampled at regular intervals and quantized in fine enough increments to meet the optical resolution requirements. These samples will be called scenes. Each scene is a digital "snapshot" of what is in the seeker's TFOV at that

TABLE II  
OPTICAL PARAMETERS

SEEKER PARAMETER	ROSETTE SCAN	CONICAL SCAN	CENTER SPUN RET.
SPIN RATE	 (Petal Rate)		
TFOV	$\pm 1^\circ$	$\pm 1^\circ$	$\pm 1^\circ$
DETECTOR WINDOW AREA	2.54 mrad.	1 mrad.	1 mrad.
OPTICAL RESOLUTION	1.8 mrad.	1 mrad.	1 mrad.

instant, and a new scene is recorded every [REDACTED] for a reticle seeker with a [REDACTED] scan rate, and [REDACTED] for a typical rosette scan simulation. These digitally coded scenes are generated by the target processor which directs the scenes to a target map (an array of digital random access memory which stores the quantized coded scene data) and formats them identical to scenes normally viewed by the seeker.

Meanwhile a second target map full of scene data is being processed by the convolution processor. Because the FOV is sampled at the spin rate (or petal rate for rosette scan) a new digitally encoded scene will be read for each spin cycle or petal of the scan. The convolution processor's job is to mask the scene with the scan pattern, a reticle, or flying spot scanner, with respect to the scene. This sum, when converted to analog and filtered, corresponds to the detector output. Once again, because the convolution processor is a digital device, the scan and its motion must be quantized, and each quantum step must be small enough to meet optical resolution requirements.

To allow both target and convolution processors as much computing time as possible without excessive system delay times, an A-B arrangement of two target maps (shown previously in Figure 2) is used to process simulator data. Control of either of these memory arrays may be given to the target processor or the convolution processor. While the target processor is filling target map A with a new digitally-encoded scene, the convolution processor is obtaining output values for the scene held in target map B. After both processors finish their tasks, control of the two target maps is exchanged, so that the target processor begins filling target map B with a new scene while the convolution processor continues generating detector output values from the new sample data set stored in target map A. At each scene update, control of the maps is once again exchanged and the process is repeated continuously throughout the simulation. Because new scenes are typically generated at [REDACTED] a target



map swap between convolution and target processors also occurs at these rates. Summaries of all data rates are given in Tables III and IV. The following sections explain how these tables were derived.

### 2.3.1 Target Processor Data Rates

The target processor must write all targets in the seeker's FOV into a target map. The rates for this transfer then depend on the size of the target map and how often a new scene must be generated. A target map size of 64 x 64 was chosen because the FOV for reticle seekers are typically 35 blur-circle diameters wide, allowing resolution of about half a blur diameter. With an actual FOV of only 20 blur diameters, the rosette scan simulator requires resolution of 0.62 milliradians so that a 64 x 64 target map is equivalent to resolution of one-third of a blur diameter. For reticle systems, a new scene must be generated every [REDACTED] to fill a 64 x 64 target map array. The target processor output data rate is then calculated to be [REDACTED]. For the rosette scan system, a target map is updated for each new petal of the scan, or [REDACTED] so the target processor output data rate is [REDACTED].

### 2.3.2 Convolution Processor Data Rates

For reticle systems, the convolution processor must mask the target map with the reticle map and sum the intensity values that remain. This sum represents a single detector output data point. The reticle is then translated by  $1.8^\circ$  and the process repeated until the convolution processor has generated output data points for a full cycle of the reticle. To prevent loss of resolution in the masking process, the reticle map, also stored in a digital memory array, has the same resolution as the target map. For conical scan, the reticle must be large enough to contain the target map describing a non-overlapping circle, so the conical scan reticle will be held in a 64 x 64 array.



TABLE III

ROSETTE SCAN PARAMETERS


---



---

FOV	64 x 64 bytes
MAX. SCAN VELOCITY	74.6K points/sec.
SCAN DWELL TIME	1/74.6K = 13.4 $\mu$ sec. per scan position
FRAME RATE	
FRAME TIME	
NO. POINTS/PETAL	202
WINDOW SIZE	3 x 3 bytes

---



---

TARGET SIZE EFFECTS

	<u>MAX. TARGET AREA = FOV</u>	<u>MAX. TARGET AREA = 1/4 FOV</u>
MAX. TARGET SIZE	64 x 64	32 x 32
TARGET PROCESSING RATE (SERIAL) PER TARGET		
SERIAL PROCESSING RATE:		
FOR 10 TARGETS		
FOR 20 TARGETS		

TABLE IV

CONICAL SCAN PARAMETERS

FOV	64 x 64 BYTES
RETICLE SIZE	64 x 64 BYTES
FRAME RATE	
STEPS PER FRAME	
STEP DWELL TIME	
STEP CALCULATION TIME	
MAX TARGET SIZE	64 x 64

SERIAL TARGET MAPPING RATE:

SINGLE TARGET	-
TEN TARGETS	-
TWENTY TARGETS	-

Previous experience with seeker simulators has shown that the convolution resolutions should be no less than 5 blur circle diameters per reticle spoke. For a  $15^\circ$  reticle spoke and one blur circle per 35/64 bytes (worst case), then one reticle revolution should be broken into 200 segments. Consequently, all memory locations in the target and reticle maps must be accessed for each segment and 200 segments must be processed for each scene in the target map, so data rates are:

for reticle system convolution processors.

Given the rosette system's optical parameters of Table II, each cell of a 64 x 64 target map array represents 0.3 square mrad. With a detector size of 2.54 square mrad., the equivalent in the array would occupy 9 cells. These cells are arranged in such a way so as to best represent the detector projection through the optical system. The detector window must scan the target map in discrete steps. The scan speed in a rosette scan varies with position, so to maintain optical resolution the window's discrete scan steps must occur often enough that successive window locations on the target map are at least adjacent.

Scan speed is highest at the center of the rosette scan pattern, and for a 64 x 64 target map it was calculated that the maximum window dwell time allowable is \_\_\_\_\_ At this rate, one petal of the scan will contain 202 steps. During each step of the scan, the convolution process is responsible for summing intensity data in the 9 cell detector window where the sum represents the detector output. Data rate for the rosette scan convolution processor is then the \_\_\_\_\_ times the number of scan samples per petal (202) times the number of target map cells in the detector window. This data rate is \_\_\_\_\_

## SECTION III

### 3.1 DESIGN IMPLEMENTATION

The ETSG design implementation is as shown in Figure 7. This design, as conceived, is a real time multispectral image plane simulation for conical scanned reticles and rosette scan seeker systems. Initialization of this system is performed by a general purpose 6800 microprocessor system. Initialization scales the ETSG to the seeker being simulated and loads twenty normalized reference targets into the twenty reference RAMS. In addition, if flares and pulsed jammers are to be used as sources, the time history of intensity for the type flare to be used, and time history of the pulsed jammer must be loaded. The normalized targets are then used to scale intensity gradients, size, shape, aspect angles, and rotation orientation. After these parameters are normalized, dynamic parameters are processed by the 20 microprocessor dynamic loader controlling processors. These processors control all dynamic parameters and the 20 target loader boards. The twenty targets are then loaded to a common FOV array and convolved with the seeker scan pattern. After convolution, the digital signals are converted to analog and output to the seeker. Each of these processes is discussed in detail in the following sections.

### 3.2 SIMULATION INITIALIZATION

#### 3.2.1 Seeker Scaling

To initialize the simulation for a particular seeker, the seeker type (i.e. scan pattern), field-of-view, reticle type if reticle scanned, SNR required for track at the simulation start, noise equivalent flux density (NEFD), system responsivity from the optical aperture to detector output, the seeker's maximum scan rate, and the optical resolution in terms of the blur diameter are inputted to the ETSG via the initialization processor.



### 3.2.1.1 Seeker FOV and Optical Resolution

The ETSG has been designed to simulate two generic classes of seekers: reticle and flying spot scan systems. The simulated FOV of all types is based on 64 x 64 resolution elements. In each case, the minimum blur diameter (diameter of a spot which contains 84% of the total power of the image of a point target) is represented by 2 x 2 elements. Thus the maximum number of blur diameters which could fill a field-of-view is 32 ( $64 \div 2$ ).

The simulation may be scaled to real systems by using the ratio of the seeker optical resolution (minimum blur diameter) to seeker FOV. For example, consider a seeker with an FOV of  $\pm .78^\circ$  and a minimum blur diameter of 0.85 mrad. Converting the FOV to milliradians (27.27 mrad.) and dividing by the blur diameter shows that 32 blur diameters fit into one FOV. The ETSG will have the proper simulation parameters.

Now examine a system with a  $3^\circ$  FOV and 1.96 mrad. blur. Converting the FOV to milliradians yields 52.36 mrad. or 26.714 points. Since the simulation is all digital, this must be rounded to 27 points. This changes the scale slightly to either  $3.032^\circ$  FOV and 1.96 mrad. blur or 1.939 mrad. blur and  $3^\circ$  FOV. Both choices are acceptable consequences of the digitizing process.

As a last example consider a system with 0.3 mrad. blur and  $0.9^\circ$  FOV. This yields 52 blur diameters within the FOV, which cannot be simulated. Either the FOV must be reduced or the minimum blur increased to the maximum ratio of 32 blur diameters across the FOV.

Therefore, to scale the simulation to a real system, the user inputs the system FOV and minimum blur to the I/O computer. The computer then calculates the equivalent digital representation and outputs an error message if the specified parameters are beyond the capabilities of the simulator. The computer uses this scale factor to adjust either the amplitude of the rosette scan or the reticle diameter.

#### 3.2.1.2 Seeker Scan

Once the seeker spatial qualities have been described, the user must select which type of seeker system will be simulated and the rate (within simulator limits) at which the seeker should scan, usually spin rate.

For the rosette, the scan is generated from two externally supplied, sinusoidal signals. During the simulation, these signals are sampled at a higher frequency to insure the desired resolution. Thus, an initial input scan rate has no meaning. It is interesting to note, however, that by changing the waveforms coming in, it is possible to generate other scans such as raster or spiral scans.

In reticle systems, the scan rate is selectable via the spin input command. This command is one byte specifying spin rate in Hz. Maximum spin rate is 120 Hz including roll and the minimum has no limit. To simulate spin down the spin command is simply changed at each target update. The spin speed accuracy will be controlled to 0.5% of the maximum spin speed (i.e. the spin period accuracy will be within  $\pm 50 \times 10^{-6}$  seconds).

If either of the reticle systems has been chosen, the I/O computer loads the reticle map, scaled by the spatial factors input previously, into the random access memory (RAM) of the convolving hardware. The reticle is loaded either from disk storage, or from a user written program on the I/O computer.

#### 3.2.1.3 Seeker Sensitivity

Sensitivity is described by the seeker NEFD, responsivity and minimum SNR required to track. NEFD as used here is the standard definition from reference 1 and is given by:

$$NEFD = \frac{4 F\#(IFOV) (\Delta f)^{1/2}}{\pi K_o K_e D_o \int_{\lambda_1}^{\lambda_2} D^*(\lambda) d\lambda}$$

where:

F# = Optical F number

IFOV = Seeker Instantaneous field-of-view  
in radians

$\Delta f$  = Seeker Noise Equivalent Bandwidth

$K_o$  = Optical Transmission

$K_e$  = Electronic Coupling Efficiency

$D_o$  = Optical Aperture in cm

$D^*(\lambda)$  = Detectivity as a function of wavelength

$\lambda_2 - \lambda_1$  = Seeker spectral bandpass

Note that in this definition it has been assumed that the detector spectral bandpass establishes the seeker bandpass. Also it is assumed that the optical transmission can be defined as an average over the detector bandpass. If these assumptions are invalid, then the spectral dependent components must be convolved to achieve an accurate value of NEFD.

System responsivity as defined here is a single number which converts the seeker irradiance H (in watts/cm<sup>2</sup>) to a detector output current or voltage. That is:

$$V_{out} = RH$$

where R is the seeker responsivity in volts per watt per cm<sup>2</sup> and H is defined as above. Alternately, if the detector is a current source, R may be defined as amps per watt per cm<sup>2</sup>. Responsivity, once defined, will remain constant throughout the simulation and the detector output voltage or current will remain proportional to the seeker irradiance.



Minimum SNR to track is defined as a single number N. The minimum signal level is then determined by:

$$H_{\min} = N(\text{NEFD})$$

and

$$V_{\text{out}} = RH_{\min}.$$

To prevent errors in the simulation, after each source has been assigned a total radiance the maximum seeker range will be calculated and displayed to the operator. This should prevent errors in initiating a simulation at a range exceeding the seeker's capability to track.

### 3.2.2 Environmental and Background Scaling

#### 3.2.2.1 Atmospheric Attenuation

An atmospheric attenuation coefficient for each spectral band is input to the I/O computer and used for all targets/sources during the simulation. As range closes, the atmospheric transmission,  $\tau_{\alpha}$  increases and is given by:

$$\tau_{\alpha} = e^{-\alpha R}$$

where

$\alpha$  = atmospheric attenuation coefficient  
in (meters<sup>-1</sup>)

R = range (meters)

Here, it has been assumed that atmospheric attenuation effects are not a primary parameter to be evaluated. Consequently it is represented by an average transmission across each spectral band.

#### 3.2.2.2 Background Irradiance

In order to calculate target contrast and SNR as a function of range, a background irradiance level must be input to the I/O computer in watts/cm<sup>2</sup>. In the case of either IR or UV this signal represents a detector output bias level. In addition, if the system is background limited, the background irradiance level increases the detector noise amplitude. However it is assumed here that the background noise component is contained in the NEFD input, and the background irradiance level serves only as an input to establish the detector dc component.

#### 3.2.3 Target Scaling

The I/O CPU uses FORTRAN routines to generate target shapes and gradients. These are stored in the target lookup RAM for use by the rest of the simulation. In addition, scale factors for changing target size, location, and intensity with range are calculated and stored within the ETSG. This greatly reduces the number and complexity of the real time calculations required.

##### 3.2.3.1 Shapes and Gradients

The definitions of shapes and gradients are tied into one operation during initialization. General algorithms have been written to create three different classes of shapes and gradients within these shapes. The three basic shapes are 1) triangular with both isosceles and right angle forms, 2) rectangular (with square as special case) and 3) elliptical (circle as special case.)

The triangle can have linear gradients as shown in Figure 8A specifying the peak value and the break points. This determines three planes for the right triangle which can be reflected about the center to produce an isosceles triangle. Proper selection of values can generate either a single slope or a uniform intensity target.

The rectangle may be specified with a single break linear gradient reflected about the center axis, Figure 8B. As with the triangle, either a single slope or uniform intensity can be treated as a special case. Alternately, a Gaussian distribution in a single dimension (y) may be specified.

Elliptical distributions can be specified by a bivariate Gaussian distribution (Figure 8D). For circular targets, linear gradients with a break radius may be specified, Figure 8E. Linear gradients are not available for an ellipse.

Target x-dimension is specified in meters. The aspect ratio can either be input directly or calculated from an input y-dimension. The I/O CPU then calculates scale factors for target sizing during range closure, ranges for target resolution, and range at which the target lookup RAM spatial resolution will be exceeded.

#### 3.2.3.2 Total Intensity

For the case of uniform backgrounds, contrast irradiance between targets and backgrounds can be mapped instead of absolute irradiance. Absolute irradiances allow for non-uniform backgrounds but require increased word length in the target map to allow for a wider dynamic range.

At initialization, the target radiance in watts/steradian is specified along with the physical dimensions. From these inputs, the average target radiant emittance in  $\text{watts/cm}^2$  is calculated. From the seeker NEFD, minimum SNR to track, and atmospheric attenuation, a maximum range is determined. A cumulative intensity dynamic range is kept and when all targets have been specified, scale factors are calculated to fit the absolute numbers to the internal number system, taking into account differences between targets, range closure, gradient dynamic range, and accumulation of all intensities. Should any or all of these factors combine to exceed the total dynamic range of  $4 \times 10^9$ , an error message will be output and all inputs will be available for update by the user to bring the total simulation into the available range. It should be noted that most seekers will not function over the dynamic range available from the ETSG.

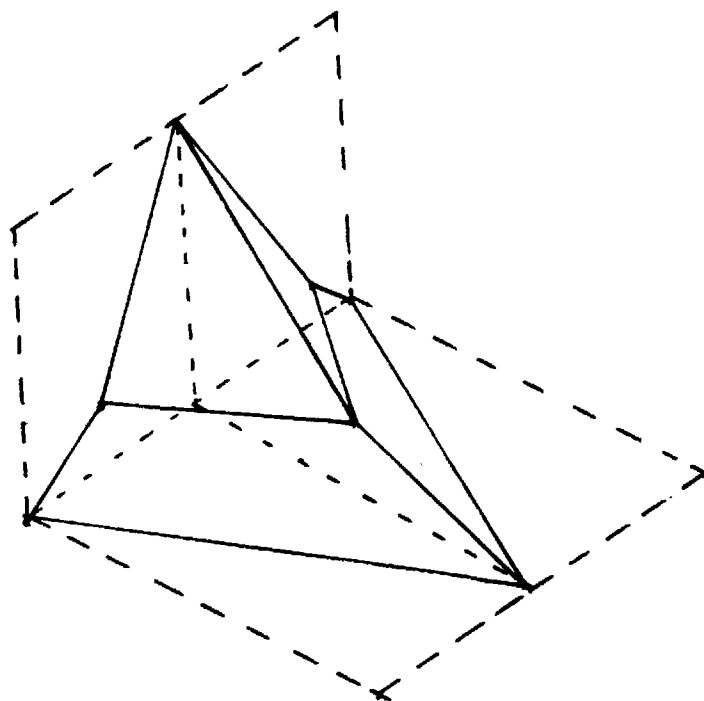


Figure 8a. Triangular Target with Linear Gradients

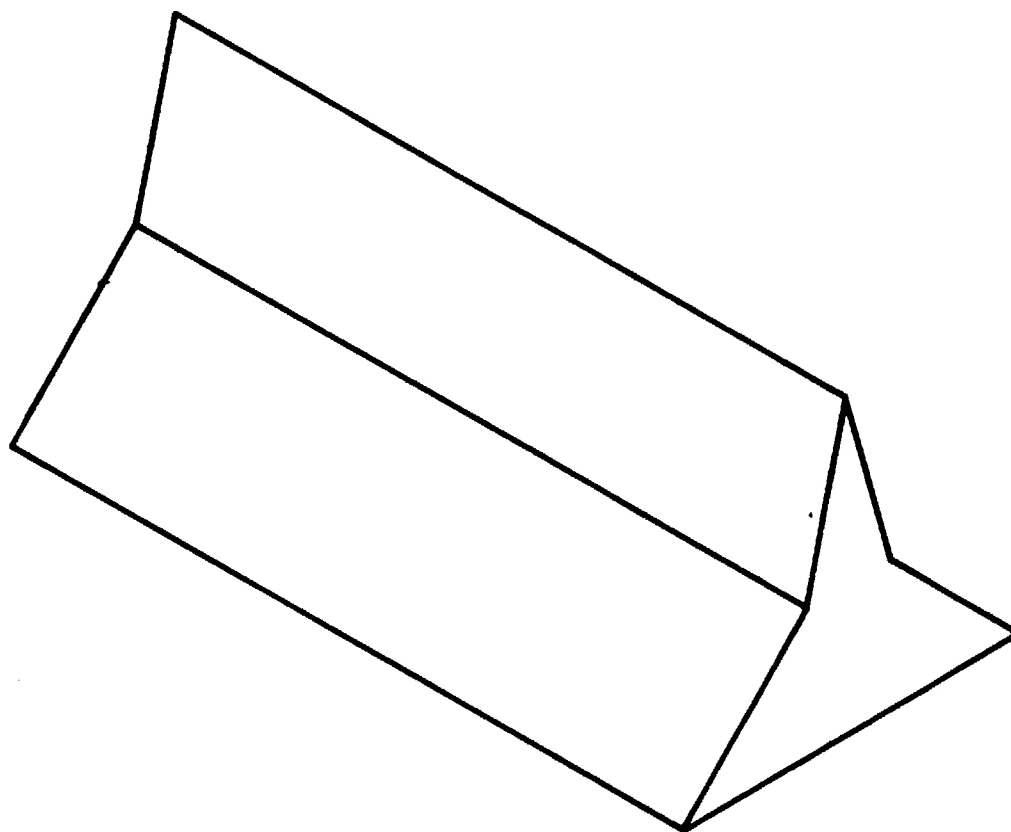


Figure 8b. Rectangular Target with Linear Gradients

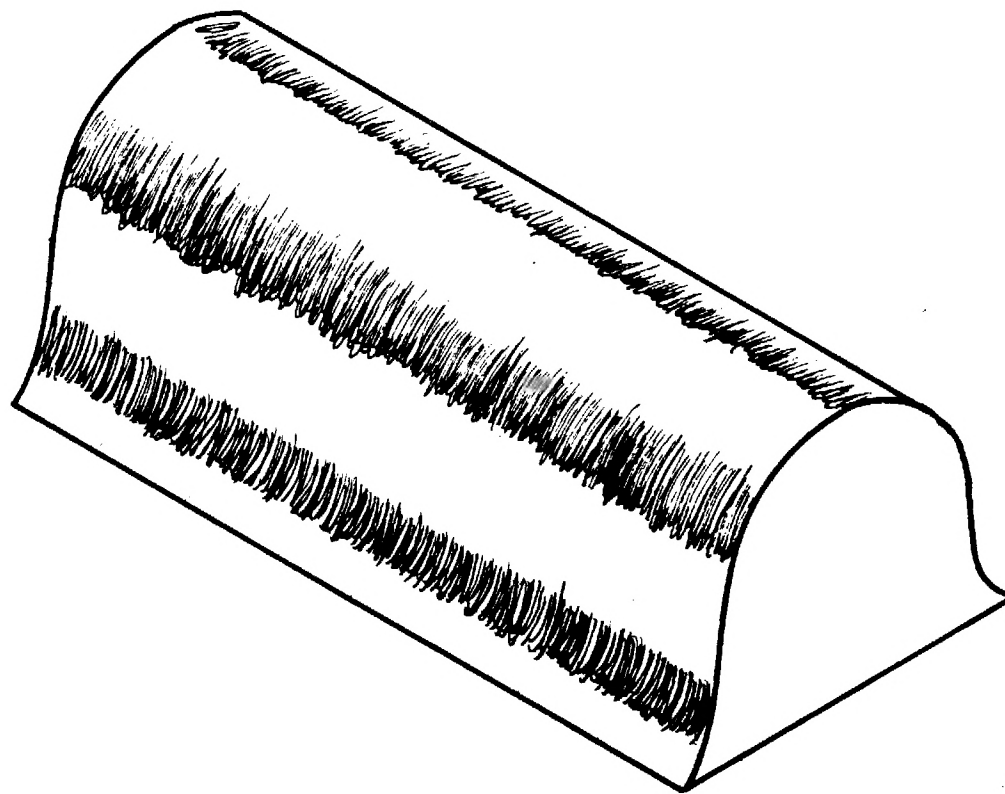


Figure 8c. Rectangular Target with Gaussian Gradients

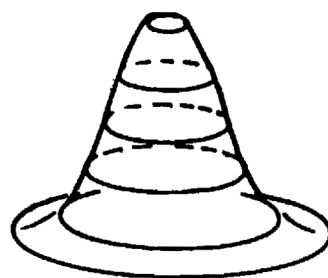


Figure 8d. Elliptical Target with Gaussian Gradients

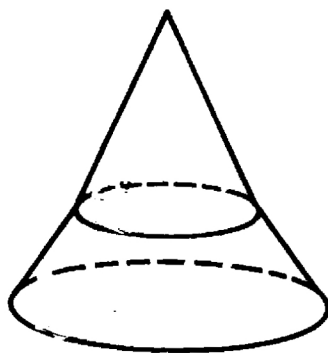


Figure 8e. Circular Target with Linear Gradients



### 3.2.3.3 Programmable Intensity

There are two enhancements available which allow specification of time-varying absolute intensities (as opposed to the changes in intensity due to range closure as a function of time). These include time histories for multiple flares and a high frequency strobe for simulation of pulse jammers.

#### 3.2.3.3.1 Flares

Any ETSG source channel may be designated as a flare. At initialization, a time history is entered as up to twenty pairs of intensity and time (Figure 9). One time history is used for all sources designated as flares, but each individual flare may be activated independently. Thus, a sequence of flares may be dispersed at regular time intervals. The intensities will follow the same time history, separated by the dispersal interval.

Once the flares have left the seeker field-of-view, they may be turned off and re-cycled through a specific chain of inputs through a source status word. Otherwise, the flare follows the time history to either the end of the history or the end of the run, whichever comes first.

The specified pairs of time and intensity are processed by the target CPU's to update the flare absolute intensity during each frame. For times between pairs, the intensity is approximated by a near-linear interpolation.

#### 3.2.3.3.2 Pulse Jammer

One target may be designated as a pulse jammer. During initialization a time varying strobe sequence is generated and stored in RAM. The strobe is a gate on detector output which is updated at the convolution rate of 20 kHz. Thus, a square wave carrier of up to 10 kHz can be simulated.

The pulse jammer may be operated as a swept frequency time burst or any special case of such (i.e., a constant frequency time burst). The

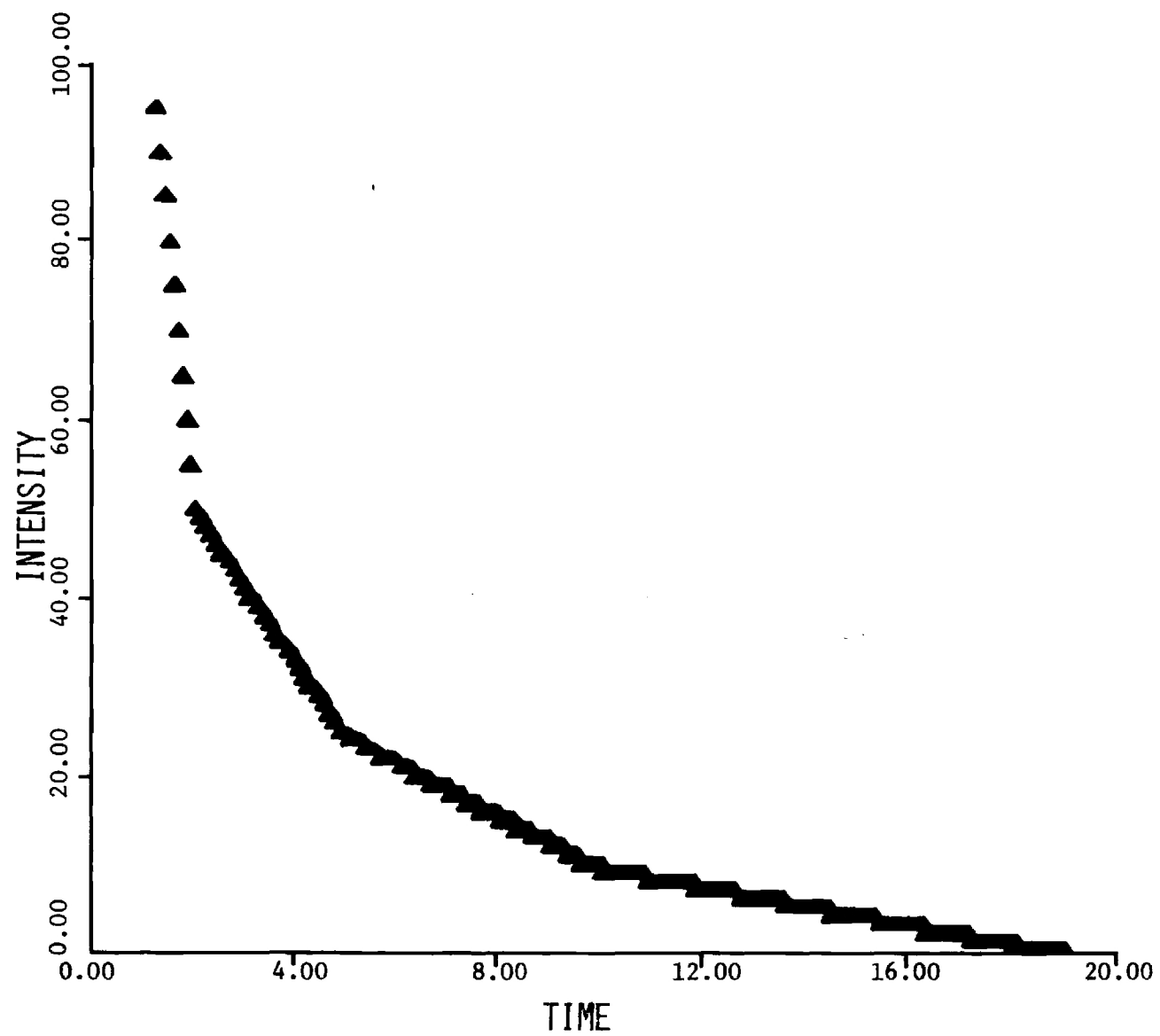


Figure 9. Flare Time History

strobe bits are stored in a RAM which will hold up to 32,768 (32K) bits, which corresponds to a maximum period of 1.64 secs of non-periodic strobe. When the end of the strobe sequence is reached, the strobe counter resets and repeats the sequence. Shorter sequences may be specified by a unique code word of less than 32K bits. The strobe may be enabled/disabled by the source status word whenever the ETSG source channels are updated (frame

---

#### 3.2.3.4 Aspect Scaling

In the ETSG, all simple targets are assumed to be cylindrically or spherically symmetric (the plume is treated differently in order to have fly-around capabilities). Views stored in the target lookup RAM's represent what is seen with the target normal to the line-of-sight. As fly-around occurs the target aspect ratio projected will be reduced due to foreshortening. This is accomplished in the ETSG by creating a lookup table in the x dimension which remaps the incoming addresses generated by the target loader circuits. As a function of aspect angle, the table is calculated to skip more or fewer points to create an effective shrinking or stretching in one dimension.

To provide a more realistic fly-around capability, two of the target circuits have been modified to accept a special form of aspect table. For these targets, three views are stored: front, side, and back. When the target is being viewed from the front, the mapping values from the table select the front view on a one-to-one basis. As aspect angle is increased, corresponding to moving around toward the side of the target, the front view is shrunk in aspect and the side view begins to stretch but may still be blocked by the front view. As the aspect changes further, the side view becomes more prominent until at  $90^{\circ}$ , the side view is mapped one-to-one. Past  $90^{\circ}$ , the back view replaces the front view and the process is reversed.

#### 3.2.3.5 Complex Targets

One problem involved with trying to simulate targets using many

relatively simple shapes is in trying to move all the pieces so that they maintain proper separation and orientation during rotation, aspect changes, and range closure. This process has been simplified in the ETSG by the use of variable origins for the target lookup RAM's, called key points. A complex target may be specified by selecting several of the simple shapes. For each shape, the target origin may be defined at up to more than 8 times the maximum target dimension from the origin of the target lookup RAM's. The actual linear value of the offset is input during initialization and scaled with the overall dimensions. An error message is output if the offset exceeds the maximum number of scaled points.

By defining the offsets from the same point in physical space (i.e. the target centroid), only one set of coordinates and orientations needs to be calculated for all the pieces which make up the complex target. This greatly reduces the overhead required in the host computer, since the data need only be duplicated. Internally, each piece can be handled independently and thus the overhead in the ETSG is also reduced.

#### 3.2.3.6 Polarity and Spectral Type

Some sources may be negative contrast, positive contrast or both with respect to background. Polarity for the run is selected during initialization. Two independent output channels are available for designation as particular spectral bands. Each target may be assigned to either output channel, with any mixture of channels between the twenty available sources.

### 3.3 TARGET CPUS

The target CPU's process range from the direct cell with pre-run calculations provided by the I/O CPU to determine target size and intensity. The target size and the target range determine the angular subtense of the target. Using the seeker FOV scale factor, the target CPU calculates an increment which will be used by the target loaders to skip

through the target lookup RAM's and produce a properly scaled image. For example, a skip factor of 2 would mean that every other point is skipped and the resulting image would be one half the size of the lookup RAM.

Also, target location from the direct call in coordinates with respect to the gimbal is converted to scaled FOV coordinates. The target CPU processes rotation into the increment set to the target loaders, as will be described later. For aspect, a bipolar, two's complement cosine is converted to sign, magnitude. The sign selects either the front or the back view for a plume and is ignored for all other targets. The magnitude selects the portion of the aspect table from which aspect mapping will be done. The magnitude also selects the proper value for the x key point calculated by the I/O CPU to keep all pieces of the complex target together.

### 3.4 TARGET LOADERS

The target loaders are high-speed, specialized circuits which scan through the target map, calculating corresponding coordinates in the target lookup RAM's. When valid points in the lookup RAM are reached, the priority encoder loads the target with the highest priority. If no valid target points occur, the corresponding target map location is filled with background (which is zero for contrast mapping). Because real-time rotation and sizing algorithms use several trigonometric functions, multiplications and other calculations, an algorithm known as Variable Path Addressing was developed.

#### 3.4.1 Variable Path Addressing

The problem is to perform a coordinate transform from the lookup RAM coordinate system to the target map coordinate system. This involves a change of scale from the normalized view stored in the lookup RAM to the proper apparent size in the target map (image plane). In addition the target must be translated and rotated to achieve the proper location and

orientation of the image in the target map. Finally, in order to facilitate simulation of complex targets by combining several simple targets, an offset can be introduced by defining a key point with coordinates other than the origin of the lookup RAM system.

Variable Path Addressing (VPA) is a method which performs scaling, rotation, and translation of an entire digital image. Although the ETSG handles all these operations simultaneously, each operation can be examined individually to show clearly what is involved.

Scaling is accomplished by skipping a number of points in the lookup RAM proportional to the reduction desired. Figure 10 shows a target map (image plane simulation) with  $8 \times 8$  elements. At the bottom is a lookup RAM with the same resolution. The circles in the target map indicate where points from the lookup RAM have been loaded using a skip factor of 2. The lower drawing shows how the target map coordinates overlay the lookup RAM coordinates. Here, the skip factor of 2 can be clearly seen. In this figure, the origin for the target map, the key point (origin for lookup RAM), and target location were assumed to be the upper left (0,0).

In Figure 11, the key point and target map origin remain the same, but the target location was assumed to be (2,1) in the target map. As can be seen in the lower portion of the graph, the target map origin's location in lookup RAM coordinates is (-4,-2) which equals the product of skip factor and target coordinate. Figure 12 shows the same target location (2,1) and map origin, but with the key point defined at (2,1). Notice that the image has shifted in the target map and also switched from odd to even elements in the lookup RAM. It should also be noted that there is no reason that the key point must be defined within the lookup RAM as in Figure 12. If the target location in Figure 11 is changed to (0,0), the same result can be obtained by redefining the key point as (-4,-2).

Although these operations have been described separately, the increments and offsets calculated by the target CPU and used by the target loaders combine all the operations into a single, simple increment. This is the feature which allows designation of complex targets and facilitates keeping the pieces together as they fly.

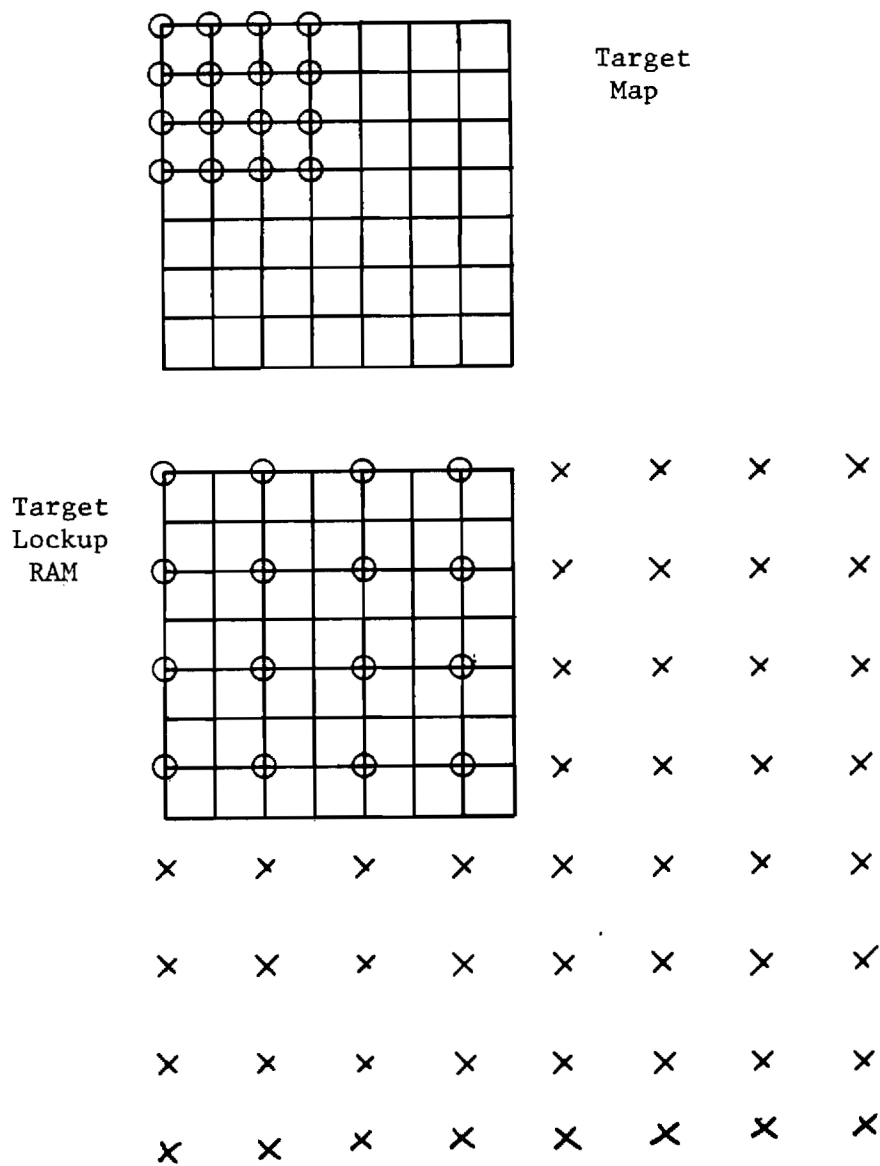


Figure 10. Scaled Target

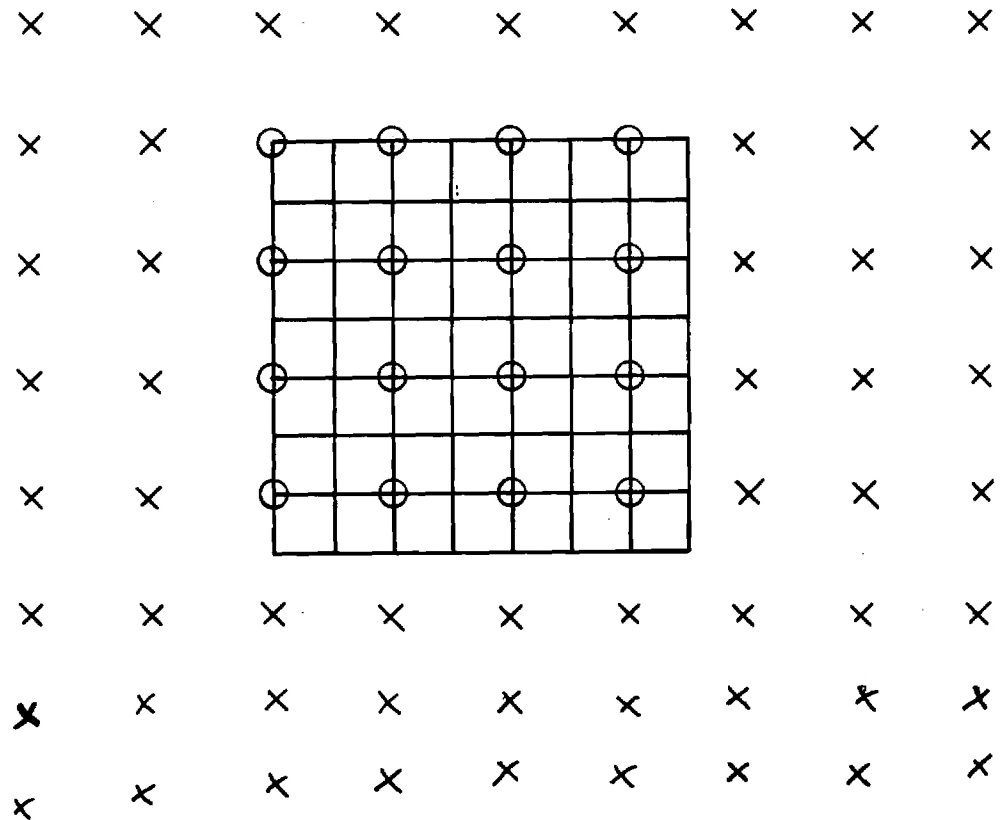
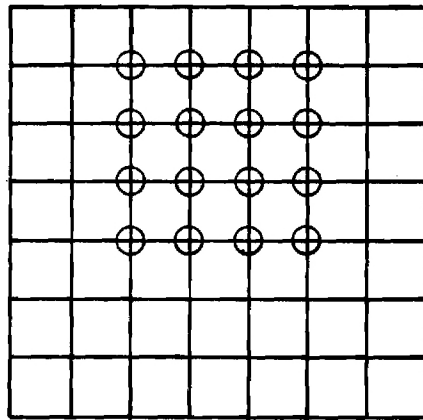


Figure 11. Target Location



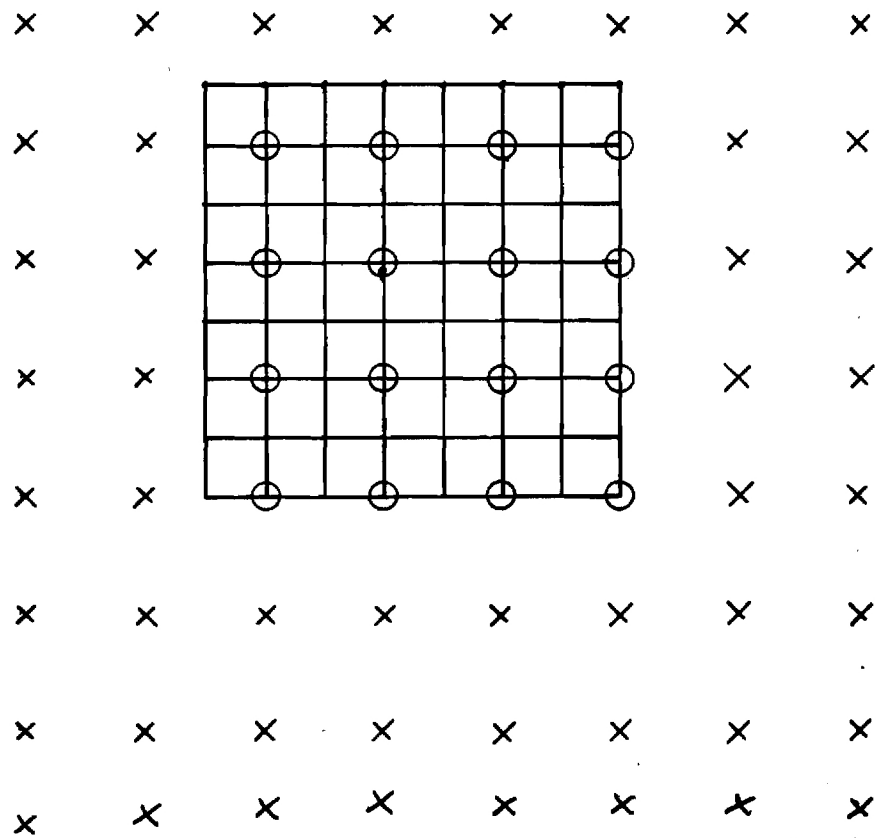
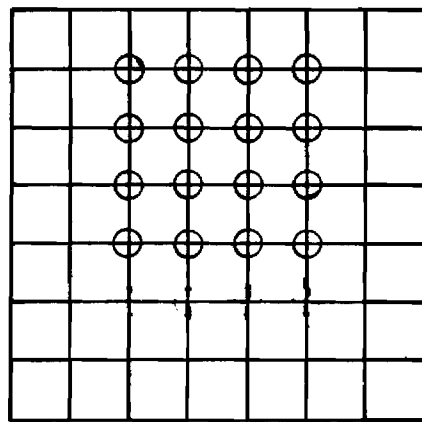


Figure 12. Key Point Location

In Figure 13 a rotation has been added to the target. With rotation, the increments through the lookup RAM's generated as the target map is scanned, must be resolved into components along the axes of the lookup RAM. To avoid errors due to truncation of the integers, a five bit fraction is carried through the calculations. The address is then taken as the whole part of the numbers in the accumulators. This assures that the maximum error in any mapping is one element in the lookup RAM.

#### 3.4.2 Priority Encoding and Loading

Accumulation of increments for all twenty targets is carried out in parallel for each point in the target map. The target loader clock provides the synchronization and has the FOV limits stored in ROM to prevent loading of any targets outside the FOV. As the loader clock scans through the target maps, lookup RAM addresses for all twenty targets are calculated. Look-ahead circuitry detects all those targets which have valid addresses (that is, those addresses which fall within the range of target lookup RAM's) and priority hardware enables the target with the highest priority for loading. The data from that lookup RAM are fed to a pipeline, floating point multiplier where it is combined with a range intensity scaling factor calculated by the target CPU. If there are no data for that target map point, background is loaded. For contrast intensity, the background, by definition, is zero.

#### 3.5 CONVOLUTION PROCESSING

The ETSG convolution processor is responsible for carrying out the real time spatial convolution of the seeker image plane with either the reticle plane or the rosette detector aperture. In the conscan case, the reticle is rotationally convolved with the image plane (target map) in  $1.8^\circ$  increments with the output connecting to the digital to analog converter. In the rosette case, convolution takes place on the image plane with the projected detector aperture following the scanning rosette pattern.

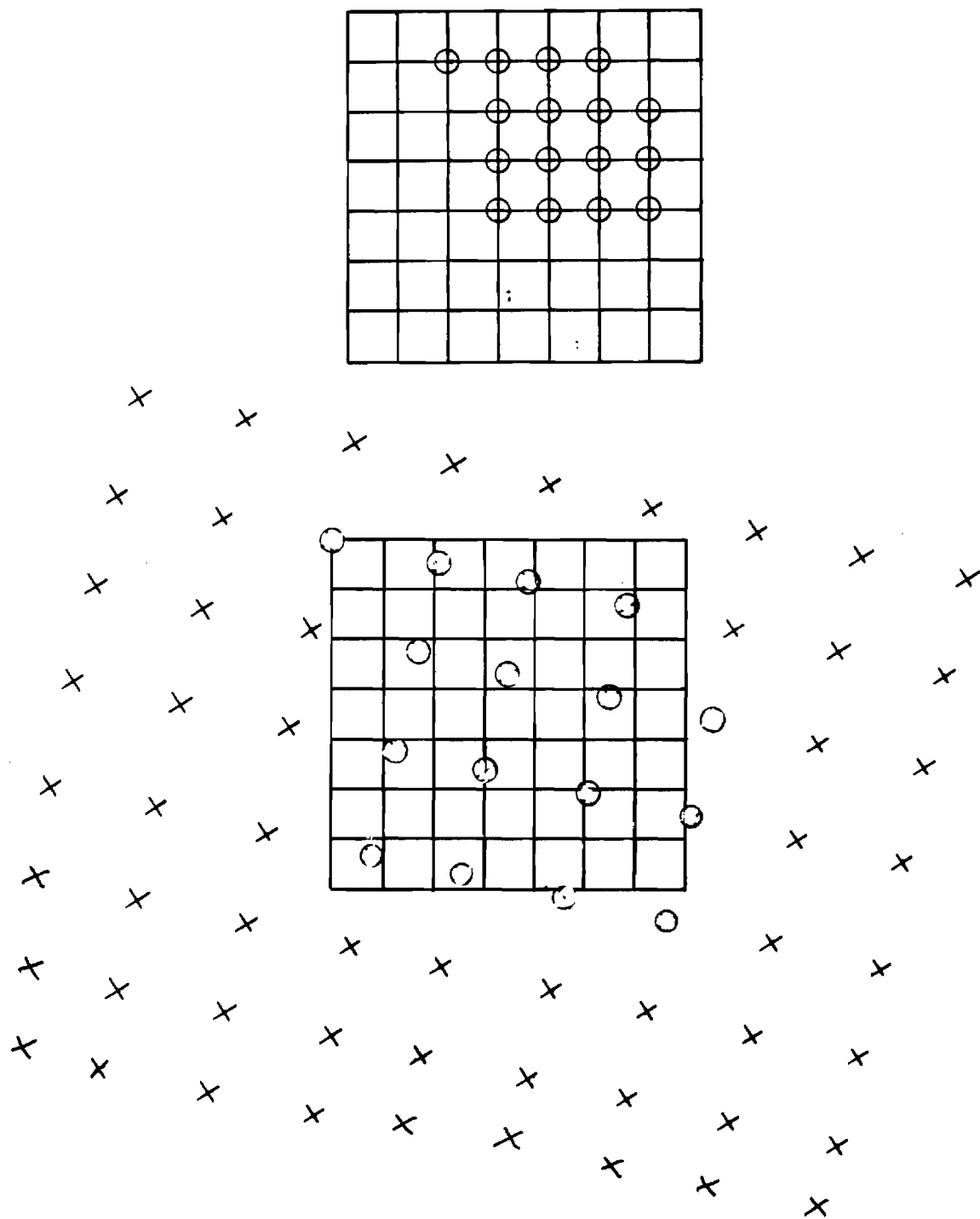


Figure 13. Target Rotation

### 3.5.1 Rosette Scan

The rosette scan input circuitry converts the rectilinear instantaneous line-of-sight seeker coordinates to respective 6-bit digital signals. These X/Y coordinates address a pixel in the target map whose data output is summed along with the surrounding 8 pixels (for a 3 x 3 detector aperture) and output to the analog converter. New samples of the scan input signals are taken and the process repeated, resulting in a stepwise continuous 3 x 3 window sampling of the target map following in a rosette pattern. The detector aperture is adjustable giving 1 x 1, 2 x 2, and 3 x 3 pixel windows. The individual pixel data are fed to the rosette convolution processor which accumulates 8-bit binary floating point intensities. After each 1, 4, or 9 pixel (depending on detector aperture size) summation, the accumulated number is output to the digital-to-analog converter and the accumulator zeroed for the next summation. The rosette scan sampling rate is 100 kHz. After each rosette petal is scanned, the A and B target maps are swapped and the process repeated on fresh target data.

### 3.5.2 Conical Scan

While target map A (or B) is being refreshed with new target data, target map B (or A) is rotationally convolved with an equal size reticle map over  $360^{\circ}$ . During convolution, target map A (or B) is split into 16 parallel sections, each 4 x 64 pixels, to facilitate the high speed summation. Each of the 16 sections has its own convolution processor and

full size (64 x 64 x 1 bit) reticle map. A reticle processor determines where on the reticle map the section overlaps the target map. The summation proceeds, each one of the 4 x 64 pixels is addressed in unison with the corresponding pixel on the reticle map. At this point, data are accumulated in the convolution processor (binary floating point adder) provided the following conditions are met:

1. There is non-zero data at that pixel,
2. The corresponding reticle pixel is a '1' (reticle clear at that point), and
3. If the data is flagged 'strobe', the strobe bit and strobe enable must be a 1.

All possible 256 pixels are accumulated and presented to the convolution summer. Once the transfer of the 16 totals to the summer is complete, the reticle processor nutates the reticle  $1.8^{\circ}$  about the null track radius, and the 256 pixel summation repeats.

### 3.5.3 Summation

After the individual conscan target map convolution processors complete their accumulations, they deposit their totals in 16 latches which are serially read by the convolution summer and the total frame intensity is accumulated. This number is then output to the digital-to-analog converter. The convolution summer is a binary floating point accumulator whose inputs are the 16 conscan convolution processors, and whose output is the digital input of the D/A converter. There are two convolution summers per spectral band; one for the positive intensities (referenced to the background), and one for negative intensities.

#### 3.5.4 Conversion For Output

The output D/A converter performs the following functions:

- 1) Converts 8 bit floating point number to an analog signal,
- 2) Scales the floating point exponent and analog signal under software control,
- 3) Provides level correction for all commands from seeker preamp,
- 4) Provides a random noise source and steady state background generator, both levels under software control,
- 5) Sums all signals into a composite analog output.

The exponent portion of the floating point number from the convolution summer is processed by binary adder/subtractors to enable scale factor and AGC adjustments. The resulting corrected 5 bit number is converted to a decoded 1 of 14 parallel format. These signals represent voltage levels which take on a value proportional to  $2^{\text{exp}}$ . The mantissa portion of the floating point number is corrected for AGC inputs, then immediately converted to an analog voltage and applied as the reference input to a 14 bit multiplying DAC. The digital input is the decoded exponent so that the resulting output of the DAC is proportional to the  $[\text{mantissa}] \times 2^{\text{exp}}$ . This analog signal is adjusted by a programmable scale factor and applied to the summing amplifier. Also applied to the input of the summing amplifier is the output of the programmable noise source, programmable background level generator and output of an alternate channel D/A converter. The resulting analog output is fed to the breadboard seeker as simulated detector audio.

### 3.6 COLOR DISPLAY AND ERROR PROCESSING

During initialization, the color display is used to check the outputs of the target generators, reticle generators, and to plot flare and pulse jammer histories. For diagnostics, the display can provide a look at the contents of the target map in non-real time, as well as verification of the contents of all RAM internal to the ETSG.

When the ETSG enters the real time phase, the dedicated display CPU takes control of the display. The display CPU has three functions:

1) to process incoming target coordinates with missile roll angle to de-roll the coordinates, 2) display all targets at the de-rolled coordinates with a different color for each class of target, and 3) to perform dynamic error checking on target ranges and dynamic roll rate.

The de-rolled coordinates are calculated by checking the dynamic missile roll angle. At maximum roll rate and minimum spin rate, this angle can be detected as being at  $0^{\circ}$ ,  $90^{\circ}$ ,  $180^{\circ}$ , or  $270^{\circ}$  within  $\pm 7^{\circ}$ . Within this detection band, a small angle approximation to sine and cosine can be used to apply a linear correction to bring the de-rolled coordinates to  $\pm 1$  point of true value. The display processor can then send the commands necessary to update a target on the color display.

Since the display processor has access to all the dynamic variables from the direct cell interface, some real-time error processing can be performed. Maximum and minimum range limits for each target are input from the I/O CPU. The display CPU checks dynamic range against these limits and outputs an error message to the color display if any are exceeded. To aid in troubleshooting, the display CPU also keeps a running maximum and minimum for all target ranges and dynamic spin rate.

#### 4.1 CONCLUSIONS

Design considerations involving both software and hardware implementations have been carefully considered in detail with the consensus favoring the hardware approach. Though required data rates appear unusually high for general purpose computers, an algorithm implemented with dedicated high speed hardware appears to be the most cost effective approach to the ETSG.

The initialization phase of the ETSG is best served by a general purpose computer capable of being programmed in a high level language such as FORTRAN. Since this is the only non-realtime phase of the system, the high level language will ease programming requirements and make the initialization phase more interactive with the operator.

A special algorithm was required to implement, in real time, the loading of the target map with image plane data. A variable path addressing scheme was designed into the high speed target loaders and look-up RAMs to achieve the 30 MHz data rate. Instead of considering each target individually to map targets at the frame rate, the variable path addressing algorithm addresses the target map one pixel at a time and relies on the target CPU's and priority overlap module to decide which if any of the targets have data to be mapped at a particular pixel.

The scan convolution phase will also be best served by parallel distributed processing, all working synchronously at frame convolution rate and asynchronously at pixel convolution rates. The primary constraint imposed on the system was to work within standard TTL speeds so 16 parallel processing circuits were designed to split the image plane target map into smaller data blocks for scan convolution.

Major problems encountered or foreseen by this design project provide no insurmountable tasks. The successful marriage of all the modules for a realistic performance will most likely be the primary effort consumer. With over 8000 integrated circuits, extensive diagnostics will be necessary



for minimum down time. There also exists a possible problem in an ETSG throughput delay uncertainty. This arises from the lack of synchronism between the CDC-6600 downloading and the ETSG's acceptance of the data. The result will be a variable phase delay component determined by the instantaneous spin phase and the "freshness" of the CDC-6600's data.